Process Modelling and Capacity Building Potential for Application of EMO Storage Concepts

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PRESENTATION PLAN

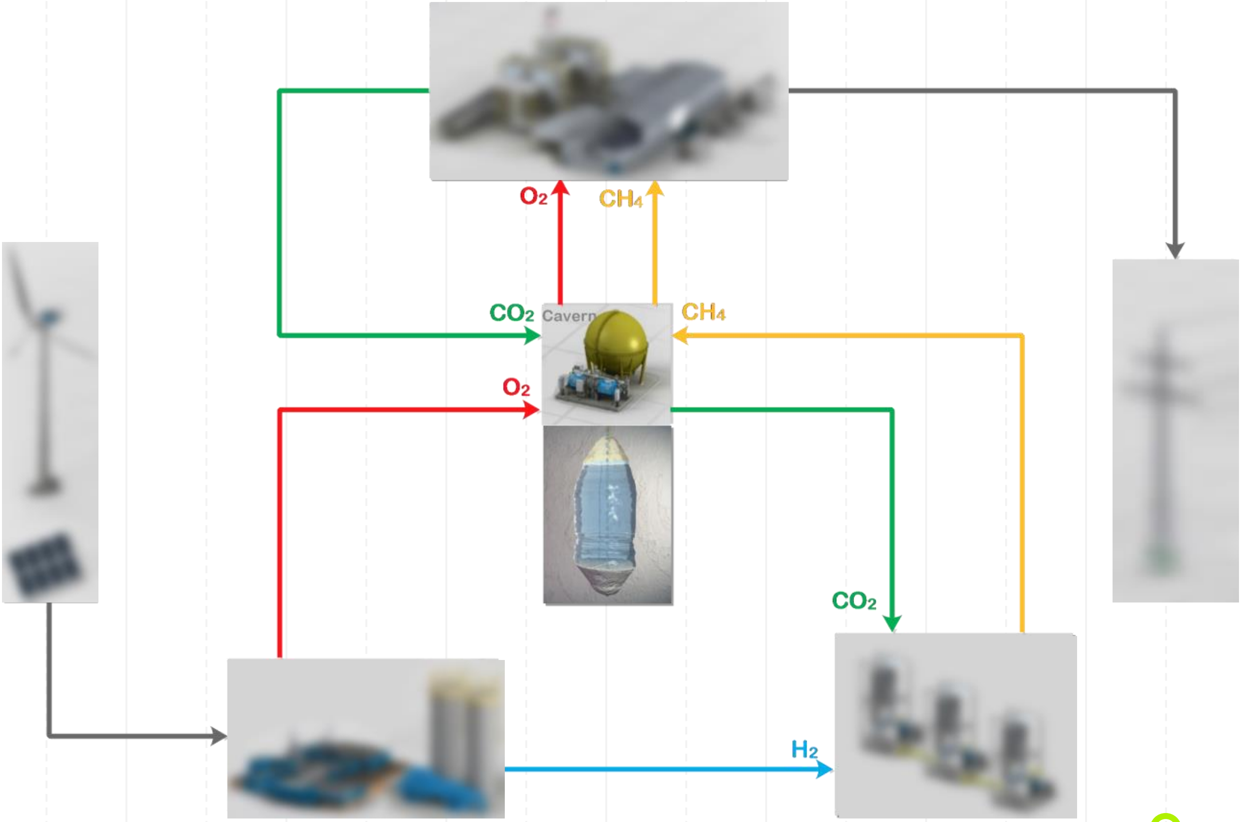
- Electrolysis, Methanation, Oxycombustion
  - Overall concept
  - Main components
- Steady state performance
  - Efficiency
  - Sensitivity analysis
- Dynamic behavior & intermittent operation
  - Transient response
  - Case study

EMO unit 1

Concept, Main components

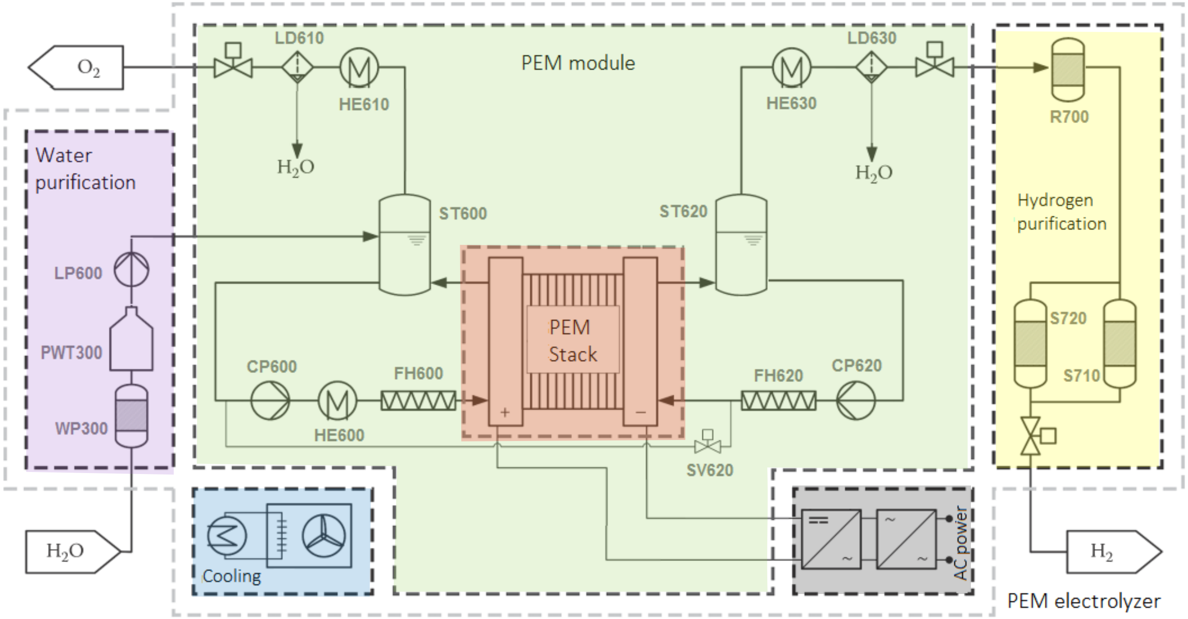
EMO CONCEPT

Power-to-Gas Electrolysis + Methanation
Gas-to-Power Oxycombustion plant
Storage underground caverns



+ Oxygen utilization
+ Easy carbon dioxide capture

PEM ELECTROLYSIS : PROCESS LAYOUT



Water purification :
Reverse osmosis and deionization

Electric conversion :
Converter and rectifier assembly

PEM stack :

Anode : $H_2O \rightarrow 0.5\ O_2 + 2H^+ + 2e^-$

Cathode : $2H^+ + 2e^- \rightarrow H_2$

Overall : $H_2O_{(l)} \rightarrow 0.5\ O_{2\,(g)} + H_{2\,(g)}$

PEM Module :
Hydrogen and oxygen loops : separator vessels, pumps, resins, water condensers

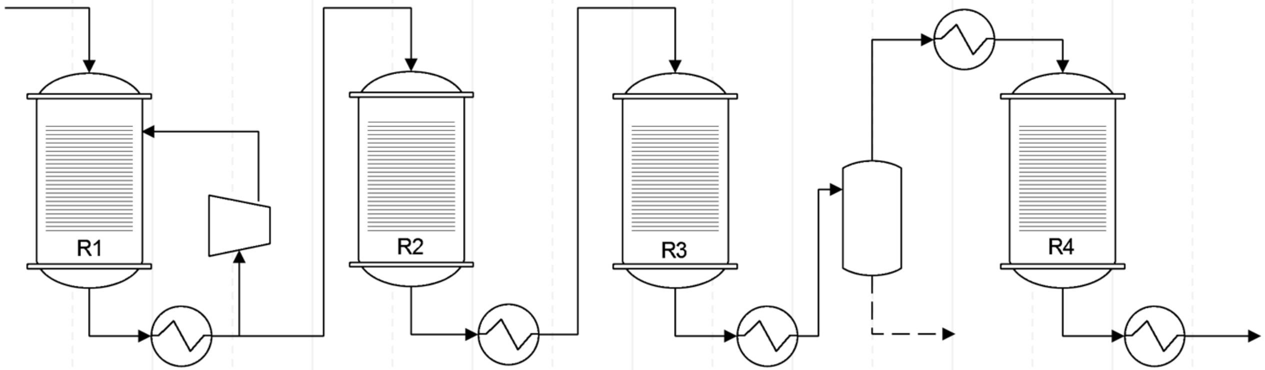
Cooling system :
Stack thermal regulation, gas cooling and rectifier cooling

Hydrogen purification :
Catalytic reaction and water adsorption

Adapted from T. Smolinka et al. (2017), PEM electrolysis for hydrogen production, CRC Press.

METHANATION : PROCESS LAYOUT

4 stages methanation based on TREMP™ Process :



CO_2 Methanation $CO_2 + 4H_2 \leftrightarrows CH_4 + 2H_2O$

CO Methanation $CO + 3H_2 \leftrightarrows CH_4 + H_2O$

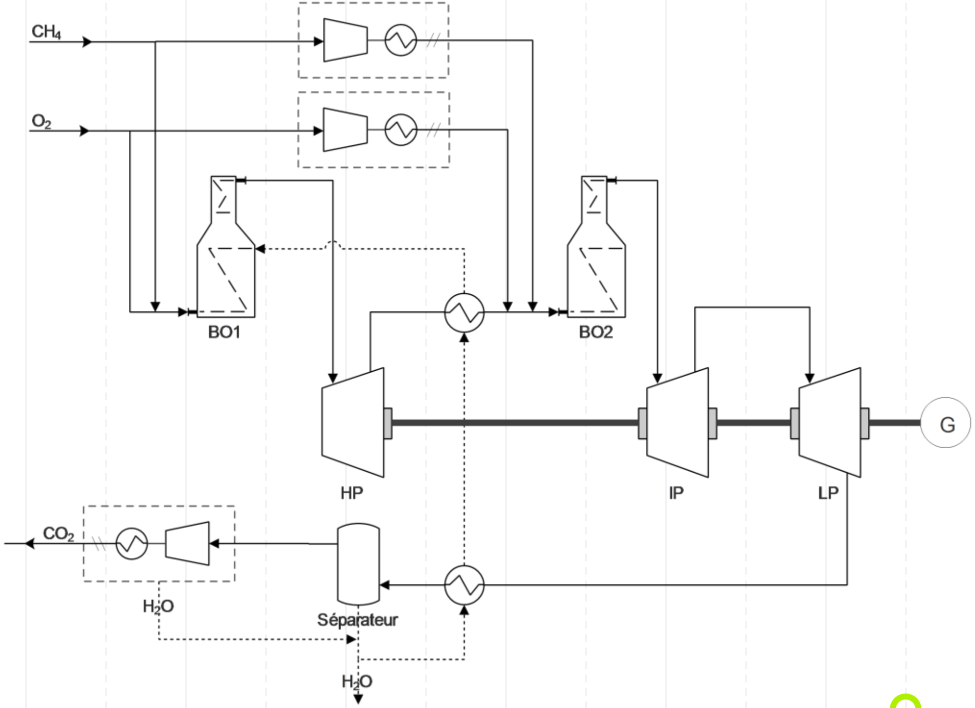
RWGS $H_2 + CO_2 \leftrightarrows CO + H_2O$

- Adiabatic fixed-bed reactors
- Catalytic reaction
- Highly exothermal reactions
- Stoichiometric ratio: $H_2/CO_2 = 4$
- Recycled flow at first reactor
- Water condensation before last reactor

OXYCOMBUSTION : PROCESS LAYOUT

The oxycombustion plant consumes oxygen produced by the electrolysis process to burn SNG and produce a CO_2 rich flue gas :

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$



- ✓ High, medium and low pressure turbines
- ✓ Steam injection at 1st oxy-boiler
- ✓ Flue gas injection at 2nd oxy-boiler

Steady state performance

Efficiency, Sensitivity analysis

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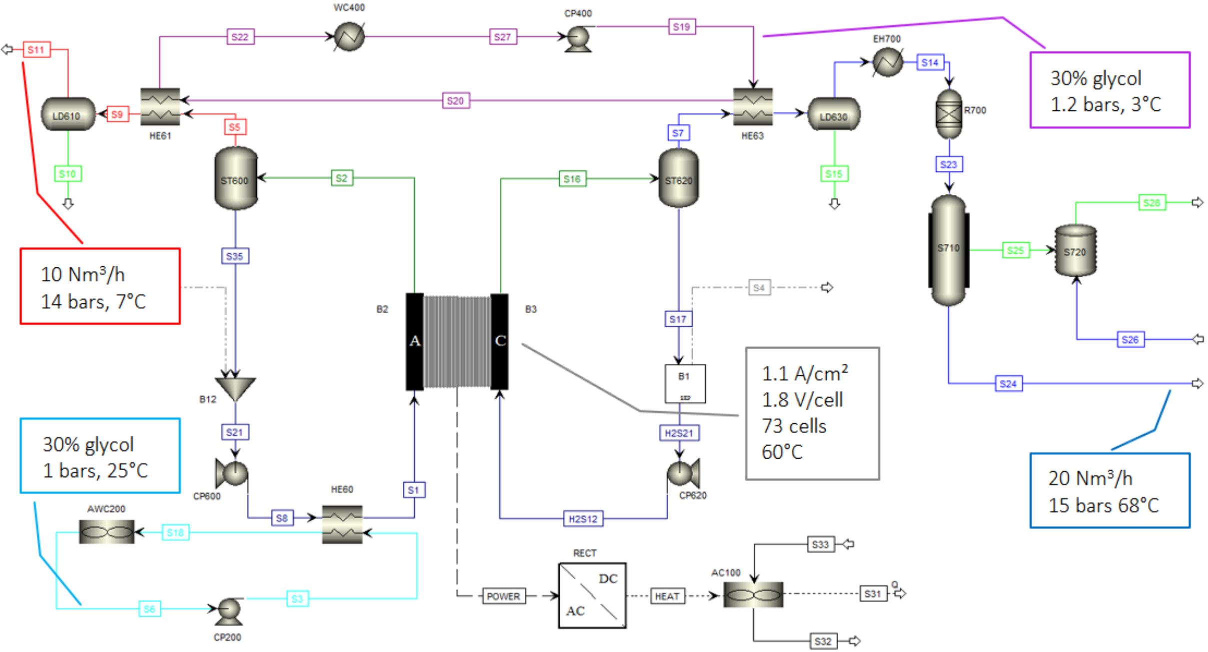
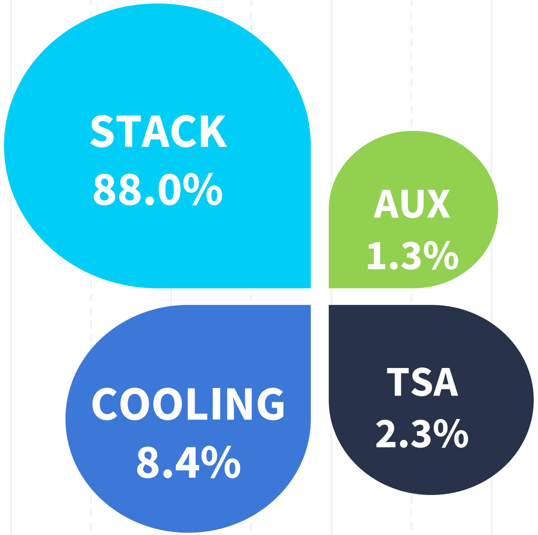
PEM ELECTROLYSIS : TEST RIG MODEL

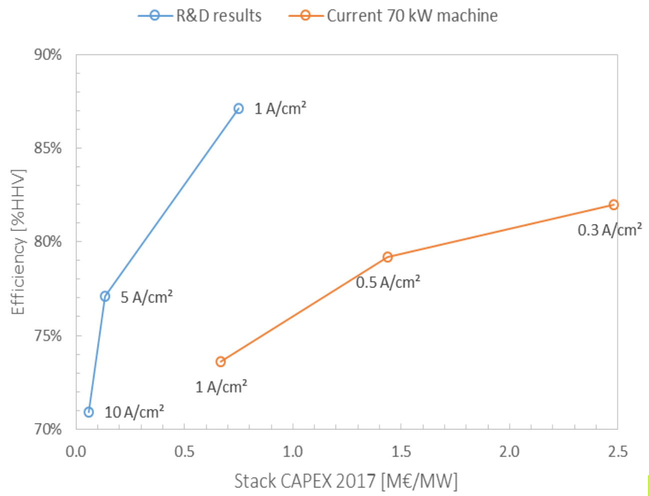


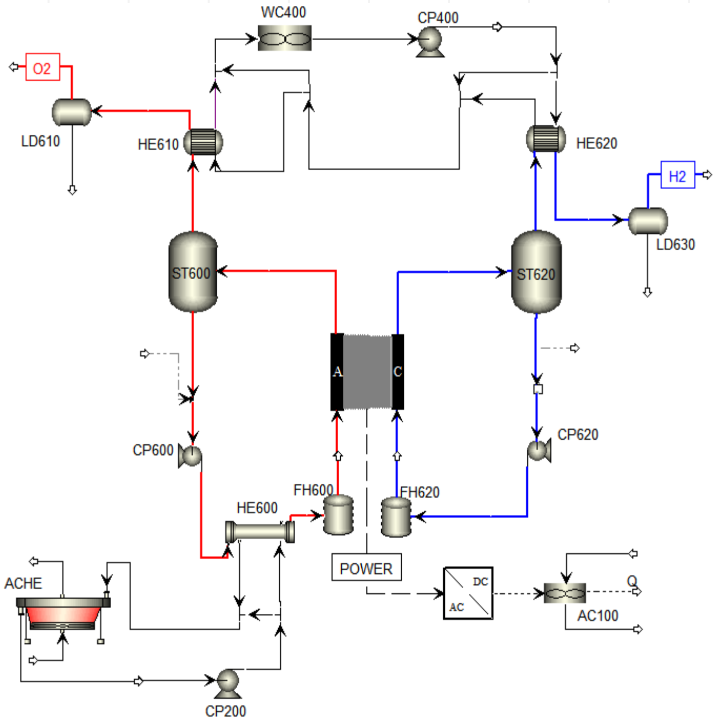


$$\eta_{PEM} = \frac{\dot{N}_{H_2,prod}\,\mathrm{HHV}}{\dot{W}_{el,Stack}/\eta_{Rec} + \dot{W}_{el,BOP}} = 65.0\%$$

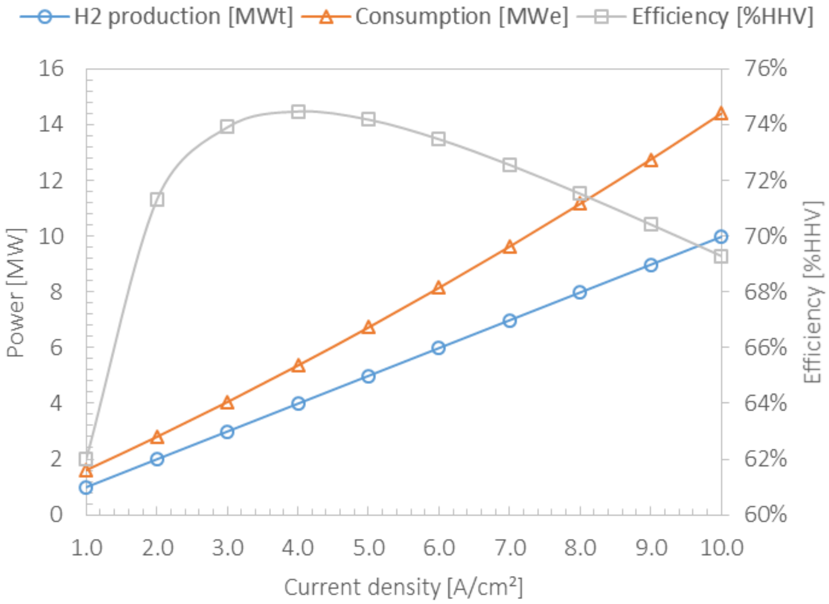
PEM ELECTROLYSIS : SCALED UP PROCESS

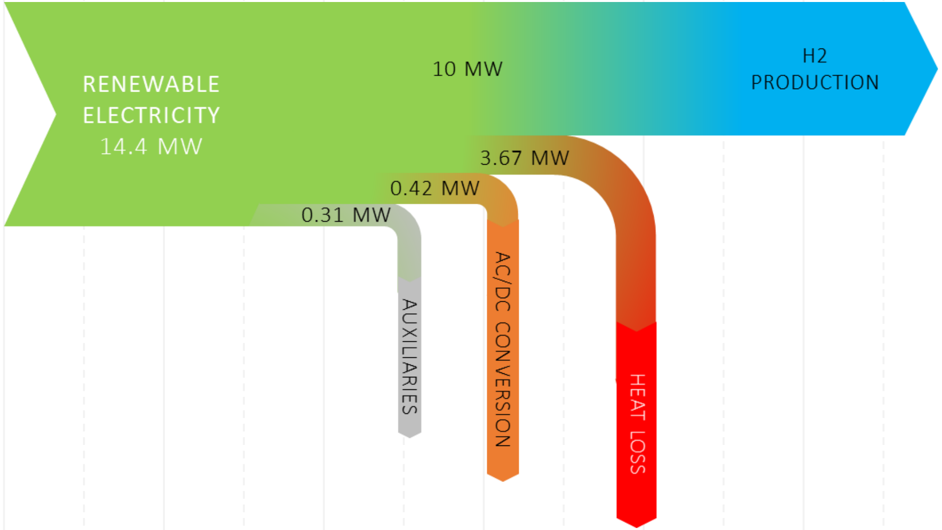
- ✓ Scale up strategy : **Modular design** to satisfy the requirements of flexibility, deployment and investment cost.
- ✓ Chosen configuration : 20 electrolysis modules of 10 MW_t each.
- ✓ Operating current density : 10 A/cm^2 for cost-effective stacks with similar energy performance.





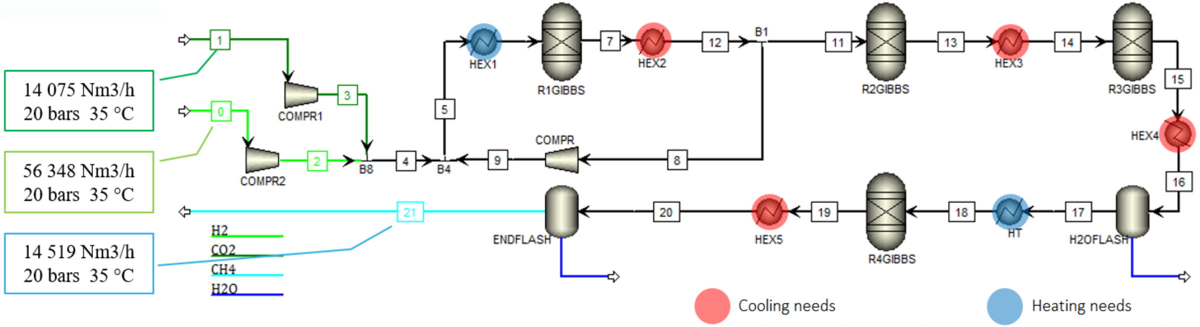
PEM ELECTROLYSIS : SCALED UP PROCESS

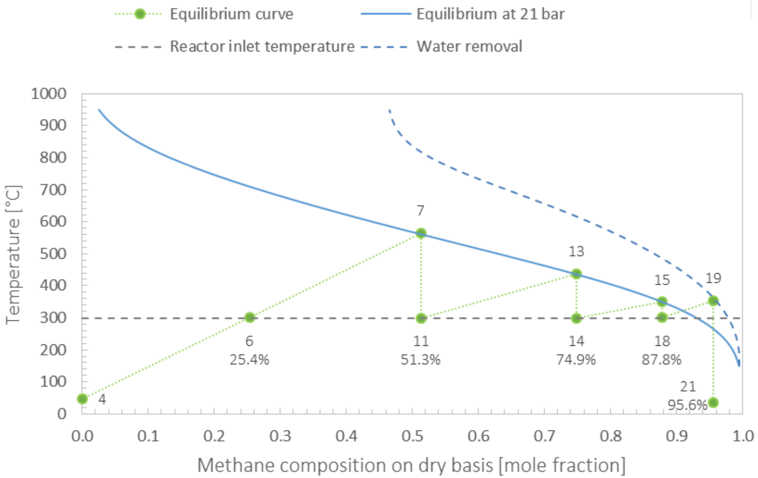




$$\eta_{PEM} = \frac{\dot{N}_{H_2,prod}\,\mathrm{HHV}}{\dot{W}_{el,Stack}/\eta_{Rec} + \dot{W}_{el,BOP}} = 69.3\%$$

METHANATION : HEAT INTEGRATION

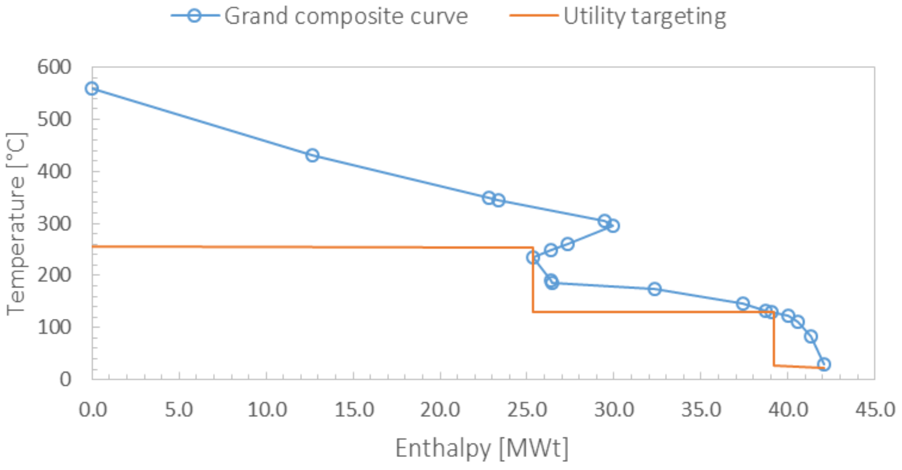




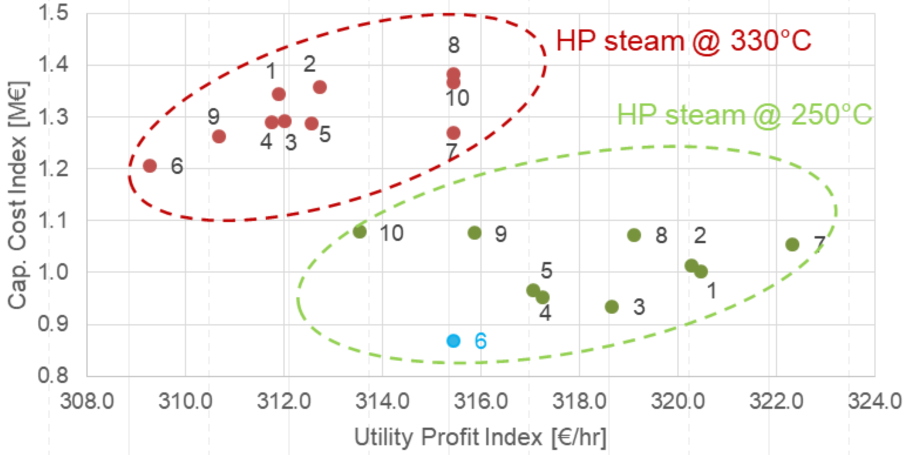
- Final product HHV : 10.73 $kW.Nm^{-3}$
- Wobbe index : 14.52 $kW.Nm^{-3}$
- CH_4 composition : 95.6%
- Available heat : 42.1 MW_t

METHANATION : HEAT INTEGRATION

- Methodology : **pinch analysis** was preformed to recover heat using an optimized heat exchanger network (HEN)
- Results : 60% recovered as HP steam at 250°C and 34% as LP steam at 125°C

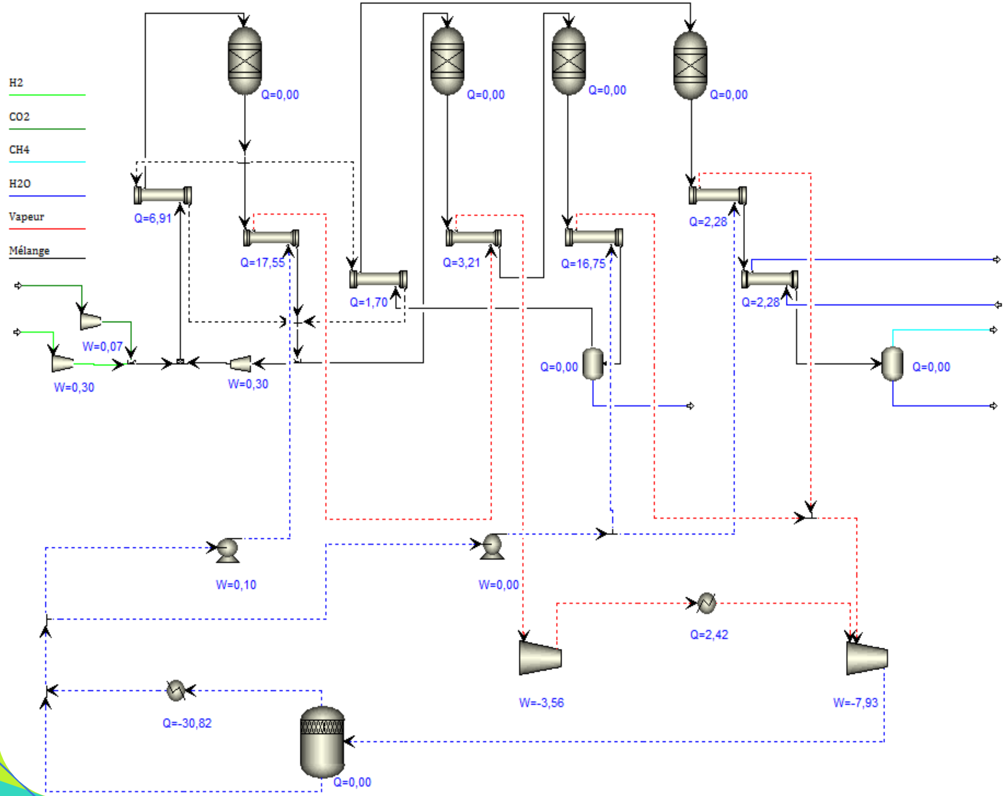


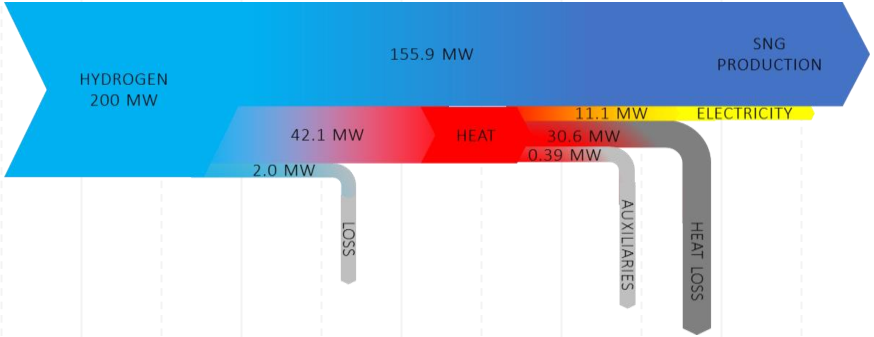
94% of available heat is recovered as steam



20 different HEN were compared to find optimal design

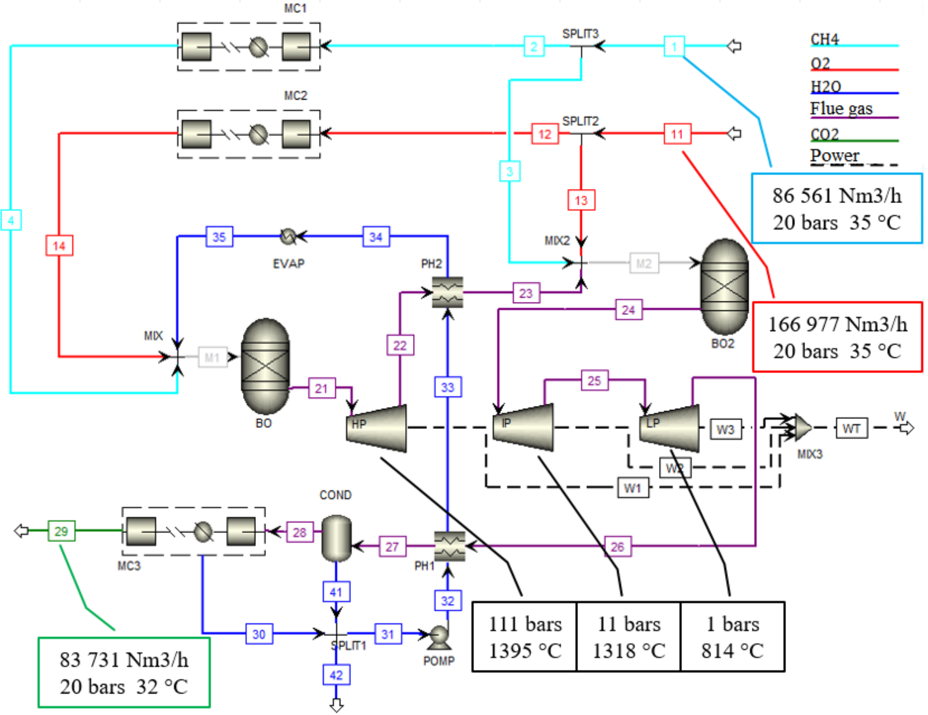
METHANATION : HEAT INTEGRATION

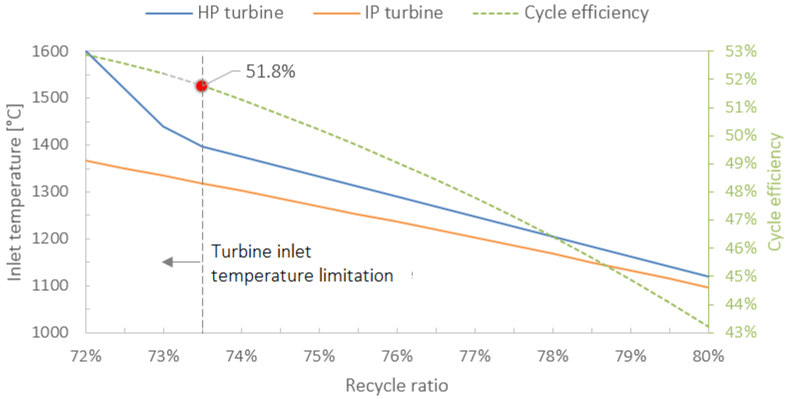


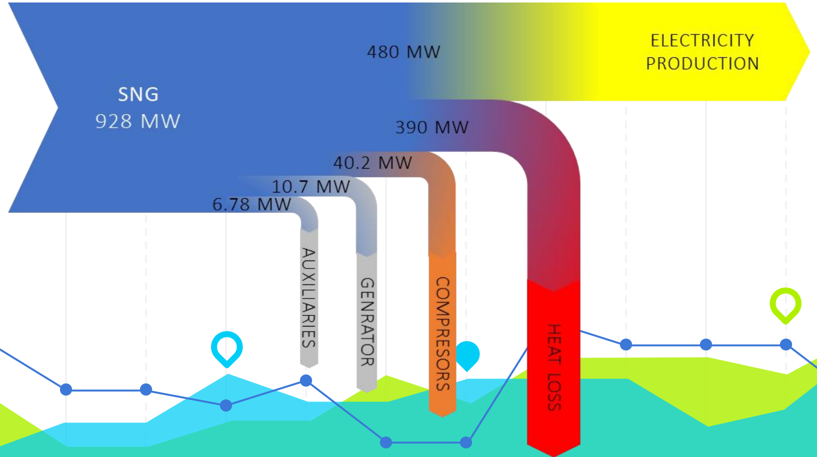


$$\eta_{SNG} = \frac{\dot{N}_{SNG}.HHV + \dot{W}_{heat}}{\dot{W}_{PEM} + \dot{W}_{aux}} = 82.2\%$$

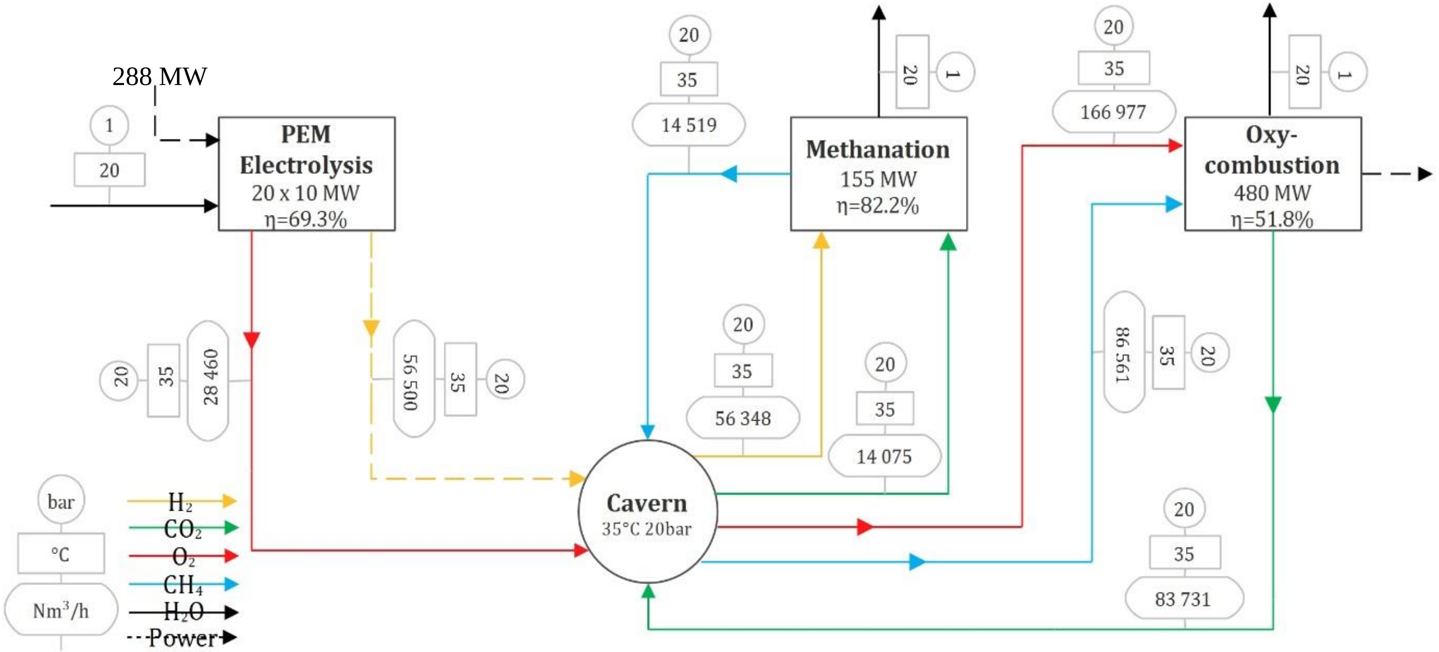
OXYCOMBUSTION : PERFORMANCE







EMO UNIT : PERFORMANCE



PtG efficiency 57.3%

Round-trip efficiency 29.7%

Power-to-Gas Dynamic Operation

Control system, Transient response, Case study

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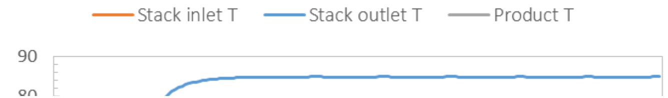
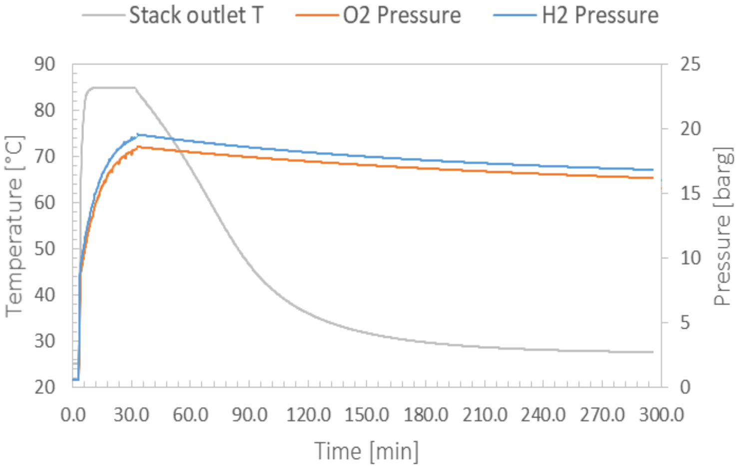
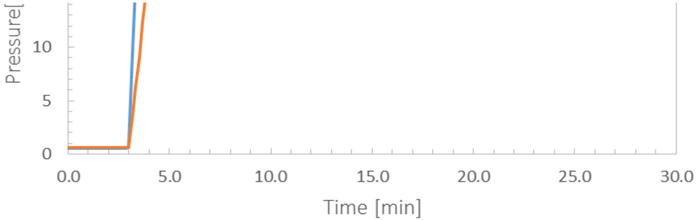
PEM ELECTROLYSIS : TRANSIENT STATE

1. **Start up phase** :
- ✓ Cold start up is performed to reach rated power
- ✓ Less than **5 min** are required to reach nominal power

2. **Standby phase** :
- ✓ System operation without hydrogen production
- ✓ Around **4 hours** before reaching room temperature



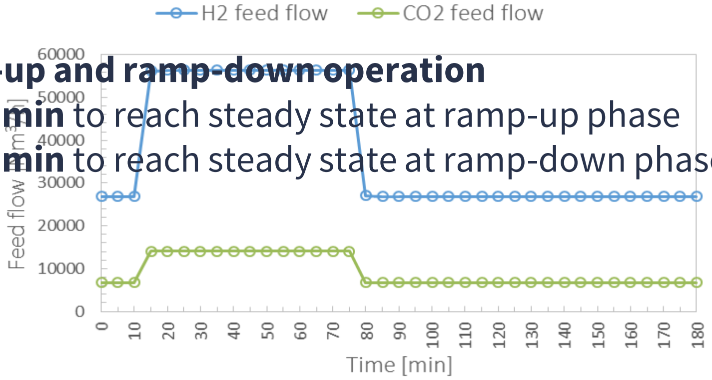




METHANATION : TRANSIENT STATE

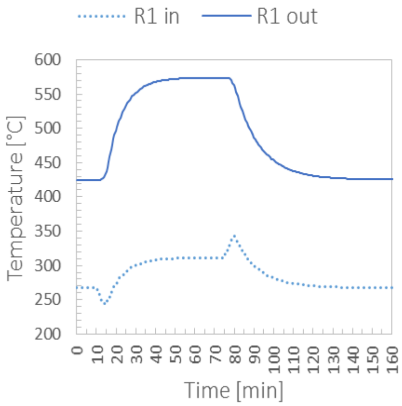
Ramp-up and ramp-down operation

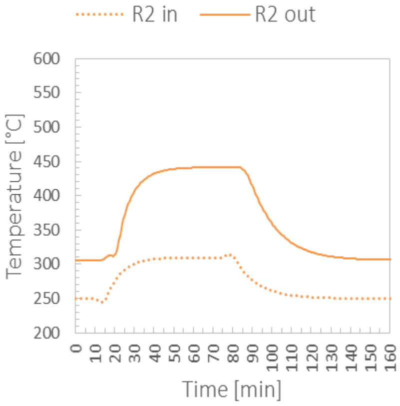
- ✓ Ramp-up : from minimal to nominal load : 48% to 100%
- ✓ Ramp-down : from 100% to 48%
- ✓ Operation range set to keep temperature between 250 and 600°C

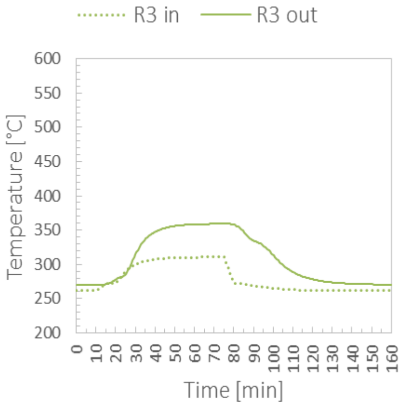


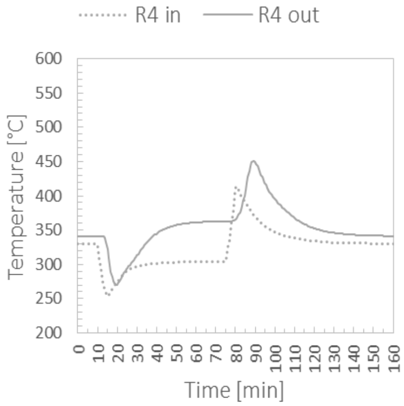
Ramp-up and ramp-down operation

- ✓ **50 min** to reach steady state at ramp-up phase
- ✓ **85 min** to reach steady state at ramp-down phase









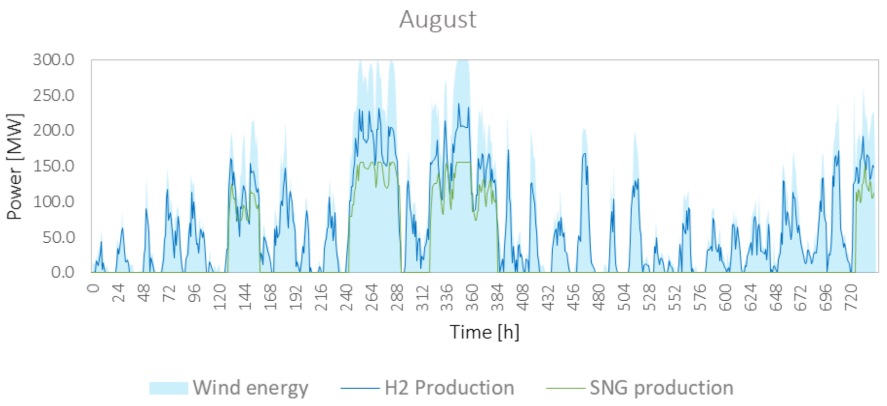
CASE STUDY : WIND ENERGY STORAGE

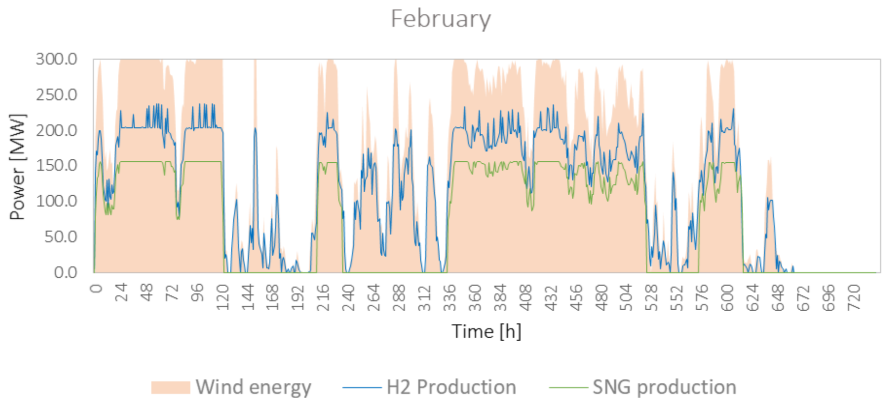
Wind park performance

- ✓ SAM tool to generate power production profiles
- ✓ Two modeled periods: summer and winter
- ✓ Rated power of 300 MW_e

Power-to-Gas

- ✓ High flexibility of PEM electrolysis system
- ✓ Limited operational periods for methanation process





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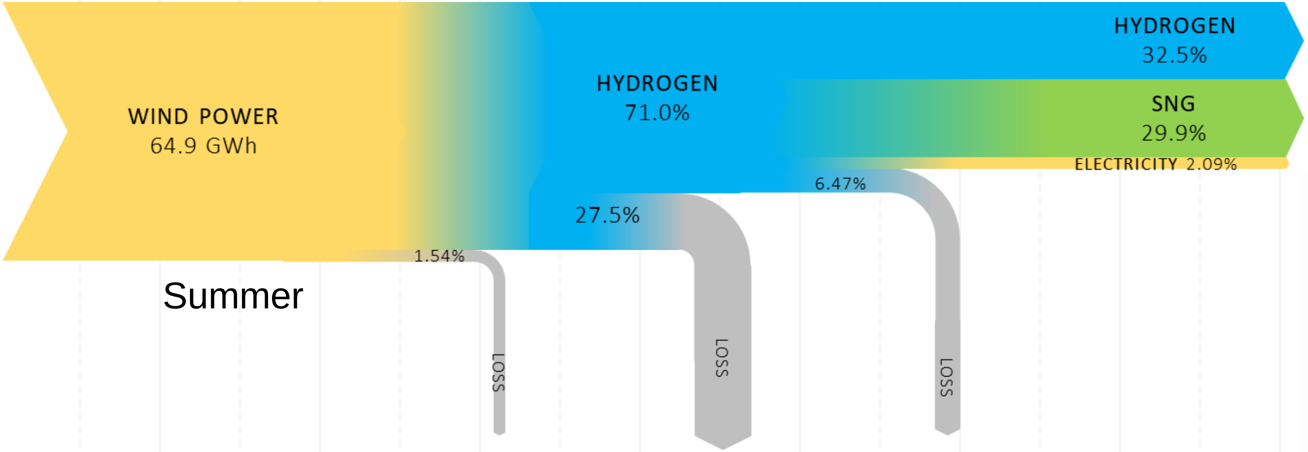
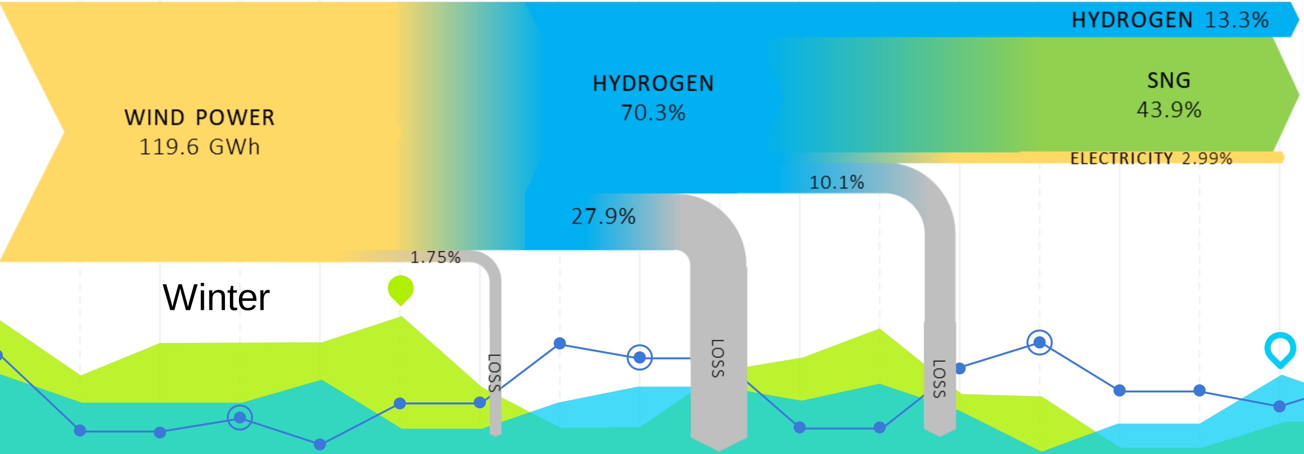
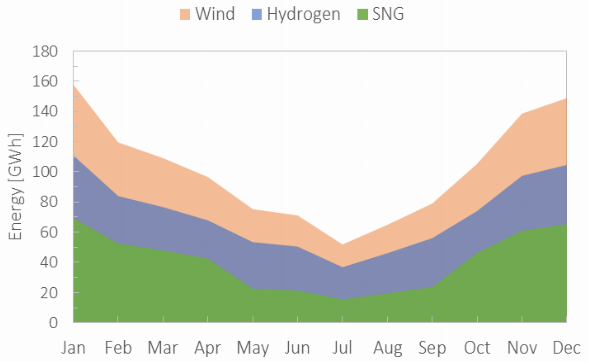


Summer



Winter

Prediction of the monthly production of hydrogen and synthesis gas from wind energy:



→ Annual consumption of 91,752 tonnes of CO_2, equivalent to an annual operating time of **560 hours** for the oxy-combustion process.

→ **6.1%** of SNG backup required

Thank you for your attention